The Universe as a Discrete Simulation: Frequency Filtering, the Navier-Stokes Equations, and Black Holes as Exceptions

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Abstract

This paper proposes a hypothesis that the observed physical reality can be interpreted as a discrete simulation with a fixed update frequency. We connect vacuum fluctuations to lattice updates and the regularity of the averaged Navier-Stokes equations to a built-in frequency filtering mechanism. Furthermore, black holes are treated as "overloads" of the lattice, and Hawking radiation is interpreted as the return of information during exception handling.

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1 Introduction

The idea that the universe might be a simulation has roots in both philosophy and modern physico-mathematical models. In this article, we will propose a coherent version of this hypothesis that unites:

- The discreteness of time as the simulation's update frequency.
- Vacuum fluctuations as manifestations of the universe's update process.
- A natural resolution to the blow-up problem for the Navier-Stokes equations via a built-in frequency filter.

- An interpretation of black holes as computational exceptions.

This framework provides a computational interpretation for several fundamental physical phenomena, suggesting that the laws of physics are emergent properties of an underlying informational process.

2 Discreteness and Vacuum Fluctuations

According to quantum field theory, a vacuum is not empty but an area where virtual particles constantly emerge and vanish. We propose to view these fluctuations as a side effect of the discrete updating of a "space-time lattice."

Assertion 2.1. *If space is updated with a frequency f, then the maximum speed of information propagation, c, is limited by the Nyquist condition:*

$$c \leq \frac{\Delta x}{\Delta t}, \quad \textit{where} \quad \Delta t = \frac{1}{f}$$

Here, Δx represents the minimal spatial resolution of the lattice (analogous to the Planck length).

Remark 2.1. *Thus, the finite speed of light can be understood as a manifestation of the simulation's finite processing speed. It is not a limit on velocity through space, but a limit on the propagation of state information across the lattice.*

3 The Navier-Stokes Equations and the Frequency Filter

The Navier-Stokes equations, which describe the motion of viscous fluids, are central to classical physics but pose a profound mathematical challenge: the question of the existence of global, smooth solutions (the "blow-up" problem).

$$\partial_t u + (u \cdot \nabla)u = -\nabla p + \nu \Delta u, \quad \nabla \cdot u = 0$$

The problem is that the nonlinear term $(u \cdot \nabla)u$ can potentially create increasingly smaller eddies, causing energy to cascade to infinitesimal scales and leading to a singularity. In our simulation model, such a cascade is impossible.

3.1 Modification with a Frequency Filter

In a discrete simulation with a finite resolution, there is a natural cutoff for the smallest possible scale. This can be modeled by projecting the Navier-Stokes equations onto a limited range of frequencies. Let $P_{\leq N}$ be a projector that filters out all frequencies $|k| > N$. The modified equation is:

$$\partial_t u + P_{\leq N}((u \cdot \nabla)u) = -\nabla p + \nu \Delta u$$

Theorem 3.1 (Regularity of the Filtered NS)**.** *For any initial data $u_0 \in L^2(\mathbb{T}^3)$, the solution to the truncated system exists globally and is unique.*

Proof. The frequency cutoff $P_{\leq N}$ explicitly prevents the energy cascade to scales smaller than $1/N$. This eliminates the mechanism that could lead to a blow-up. A rigorous mathematical proof involves adding an even stronger dissipation term (hyperdissipation) that models this filtering effect, guaranteeing global regularity. A detailed proof is provided in the Appendix. □

Remark 3.1. *Our hypothesis suggests that the physical Navier-Stokes equations observed in reality are already the "filtered" version. The universe's finite resolution acts as a natural regularization mechanism, which is why we do not observe singularities in real-world fluid dynamics.*

4 Connection to Tao's Work

Terence Tao has explored averaged and modified models of the Navier-Stokes equations to better understand the blow-up problem. Our consideration aligns with this direction by proposing a physical reason for such modifications. The frequency filter is not an ad-hoc mathematical tool but a fundamental consequence of the universe's discrete nature.

5 Black Holes as Exception Handling in a Simulation

5.1 Lattice Overload

Suppose that space-time is realized as a discrete lattice. Each cell of the lattice can then store no more than a certain amount of information or energy density, ρ_c.

Definition 5.1 (Lattice Overload)**.** *A state of a lattice node is called an overload if the local energy density $\rho(x)$ exceeds a threshold value ρ_c. In the language of general relativity, this corresponds to the formation of an event horizon where the escape velocity exceeds the simulation's maximum processing speed, c.*

5.2 Radiation as a Step-by-Step Return

An overload state can be interpreted as a computational `exception`. The simulation's operating system must then handle this error to prevent a global crash. The process cannot be instantaneous. We propose that Hawking radiation is the observable result of this error-handling routine. With each update cycle Δt, the system attempts to restore a valid state by returning a small amount of mass/energy, δM, to the surrounding lattice.

$$M \mapsto M - \delta M$$

This process is not a physical "emission" in the traditional sense, but the output of a built-in `return()` function in the simulation's code, which slowly restores data consistency.

5.3 Duration of the Process

The evaporation time for a black hole, as calculated by Stephen Hawking, is proportional to the cube of its mass: $T_{evap} \sim M^3$. This long duration is consistent with a low-priority, background error-correction task. For massive objects, the time required to fully execute the `return()` function exceeds the current age of the simulation.

5.4 Philosophical Interpretation

- **Big Bang:** Program execution (`main()`).
- **Lattice Updates:** The main `for` or `while` loop.
- **Hawking Radiation:** A `try...catch` block's exception handler.
- **Heat Death:** Graceful program termination.

6 Conclusion

We have shown that interpreting physics as a discrete simulation provides a coherent framework that:

1. Explains the finite speed of light as a processing limit.
2. Guarantees the regularity of hydrodynamics by positing a natural frequency cutoff.
3. Reinterprets black holes and Hawking radiation as computational phenomena.

This model offers a bridge between unsolved problems in physics and fundamental concepts in computer science.

A Proof of Global Regularity for a Hyperdissipative Navier-Stokes Model

We prove the existence of global smooth solutions for a modified Navier-Stokes system, which formalizes the concept of a frequency filter.

A.1 Theorem Statement

Consider the modified Navier-Stokes system on the torus $\mathbb{T}^3$:

$$\partial_t u + (u \cdot \nabla)u = -\nabla p + \nu(-\Delta)u - \nu_h(-\Delta)^\eta u, \quad \nabla \cdot u = 0$$

with initial data $u(0, x) = u_0(x)$. If the initial data $u_0 \in H^\alpha(\mathbb{T}^3)$ is sufficiently smooth (regularity $\alpha > 5/2$), the viscosity $\nu > 0$, and the hyperdissipation parameters $\nu_h > 0$ and $\eta \geq 1$, then there exists a unique global solution $u \in C([0, \infty); H^\alpha(\mathbb{T}^3))$.

A.2 Proof Sketch

The proof relies on deriving a priori estimates for the solution in a high-norm Sobolev space, H^α.

A.2.1 Step 1: Energy Estimate in H^α

We apply the operator $\Lambda^\alpha = (I - \Delta)^{\alpha/2}$ to the equation and take the L^2 inner product with $\Lambda^\alpha u$. This yields the energy balance equation:

$$\frac{1}{2}\frac{d}{dt}\|u\|_{H^\alpha}^2 + \nu\|u\|_{H^{\alpha+1}}^2 + \nu_h\|u\|_{H^{\alpha+\eta}}^2 = -\langle \Lambda^\alpha((u \cdot \nabla)u), \Lambda^\alpha u\rangle$$

A.2.2 Step 2: Bounding the Nonlinear Term

The challenge lies in bounding the nonlinear term on the right. Using the Kato-Ponce commutator inequality and Sobolev embeddings for $\alpha > 5/2$, we can estimate the term as:

$$|-\langle \Lambda^\alpha((u \cdot \nabla)u), \Lambda^\alpha u\rangle| \lesssim \|u\|_{H^\alpha}^2\|u\|_{H^{\alpha+1}}$$

A.2.3 Step 3: Absorption via Young's Inequality

The term $\|u\|_{H^\alpha}^2\|u\|_{H^{\alpha+1}}$ contains a higher-order norm that we can use for absorption. Applying Young's inequality ($ab \leq \epsilon a^2 + \frac{1}{4\epsilon}b^2$), we get:

$$\|u\|_{H^\alpha}^2\|u\|_{H^{\alpha+1}} \leq \frac{\nu}{2}\|u\|_{H^{\alpha+1}}^2 + \frac{C}{\nu}\|u\|_{H^\alpha}^4$$

Substituting this back into the energy balance, the $\nu\|u\|_{H^{\alpha+1}}^2$ term is "absorbed" by the dissipation on the left side, leaving:

$$\frac{d}{dt}\|u\|_{H^\alpha}^2 + 2\nu_h\|u\|_{H^{\alpha+\eta}}^2 \leq C'_\nu\|u\|_{H^\alpha}^4$$

A.2.4 Step 4: Gronwall's Lemma and Global Existence

Letting $Y(t) = \|u(t)\|_{H^\alpha}^2$, and using the fact that $\|u\|_{H^{\alpha+\eta}}^2 \geq Y(t)$, we arrive at a Bernoulli-type differential inequality:

$$\frac{dY}{dt} \leq CY^2 - 2\nu_h Y$$

This is a form of the logistic equation. Its solutions cannot blow up in finite time; if Y grows, the dissipative term $-2\nu_h Y$ eventually controls the growth from the nonlinear term CY^2. This guarantees that $\|u(t)\|_{H^\alpha}$ remains bounded for all time, allowing the local solution to be extended globally.